D1.5 – Design and evaluation framework and measuring tools

Empowering and Participatory Adaptation of Factory Automation to Fit for Workers

Abstract

Smart factories are characterized by increasing automation and increasing customization. In these dynamic environments, flexible and adaptive work organization is crucial both for productivity and work satisfaction.

The Factory2Fit project will support this development by creating adaptation solutions with which people with different skills, capabilities and preferences can be engaged, to become even more motivated and productive members of the work community in manufacturing industries. This deliverable describes the initial work well-being framework that will be used in the project in the design and evaluation activities. The framework integrates the viewpoints of user experience, user acceptance, usability, safety and ethics. These five viewpoints will be used in designing the Factory2Fit solutions that include both new work practices and new tools facilitating the practices. Factory2Fit solutions should contribute to work well-being by increasing job satisfaction, job motivation and work engagements. The framework also includes methods and tools to study these consequences. The initial framework presented in this deliverable will be refined based on experiences in using it in design and evaluation activities during the project. The framework will be complemented with quantitative and qualitative measuring tools. In this first version of the deliverable we introduce a selection of potential methods that can be utilized.

Keywords:

Human-centred design, methods, framework, user experience, user acceptance, usability, safety, ethics, well-being at work, job satisfaction, work engagement

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Executive Summary

This deliverable has several purposes. (1) It provides the framework for supporting Factory2Fit project activities, for designing and evaluating new solutions in the project as well as evaluating their effect. Furthermore (2), the most appropriate methods and tools are briefly presented in this deliverable so that during the project, project members can easily find the method for the need in question. (3) This deliverable also provides evidence of advances towards the achievement of project objectives as it will be updated on M18 and M24. Finally (4), the Factory2Fit framework provides a new framework for supporting and enhancing well-being at work, based on designing new tools to support work performance in the work environment.

Factory2Fit framework is coined as work Well-Being Framework. It contains three main parts: antecedents (or work context), Factory2Fit design and evaluation approach, and consequences, referring to well-being at work as well as company benefits.

In more detail, the main parts are as follows:

- The antecedents describe the context into which we are proposing the new intervention, i.e., new tools and the related work practices.
- The design and evaluation approach is embedded in the framework, supporting the design and evaluation activities related to the tools and practices to be designed in the project. According to the approach, the Factory2Fit solutions will be designed and evaluated focusing on user experience, user acceptance, usability, safety and ethics.
- The new solutions should have wider consequences on personnel's work well-being, especially on job satisfaction, job motivation and work engagement. These consequences will also be studied. Factory2Fit solutions should also lead to company benefits on optimized processes, productivity, and quality, and they should affect company image so that the company becomes as a more desired place to work. In the following, we will describe in detail the work well-being framework, focusing especially on the central design and evaluation part of it.

In the deliverable, the most promising methods or approaches are listed with the corresponding reference. They include the perspectives user experience, user acceptance from the tool acceptance point of view, usability of the tools, safety, ethics, well-being, job satisfaction, job motivation, work engagement, and facilitating factors. Thus, the methods are in accordance with the project framework.

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1 Introduction

Factory2Fit project will develop in parallel new work practices and new work tools that facilitate those practices. For the design of those practices and tools, we will use different approaches depending on the phase of design and the targets of the design or evaluation activity. The overall goal of the Factory2Fit solutions is to contribute to work well-being and productivity. In this deliverable, we describe the Factory2Fit Work Well-being Framework based on several complementary design and evaluation approaches.

1.1 Purpose of the Document

This deliverable describes the Work Well-being Framework to be used in the design and evaluation activities of the Factory2Fit project. The framework includes methods and tools to study work practices and tools as well as methods and tools to study wider impacts on work well-being. The deliverable describes the different viewpoints included in the framework as well as existing methods to support design and evaluation activities.

1.2 Intended readership

The deliverable is targeted to Factory2Fit partners who plan and carry out design and evaluation activities. In addition, this public deliverable can be utilised by anyone who wants to learn how to design and evaluate for work well-being from the viewpoint of work tool development and task support related innovations.

1.3 Relationship with other Factory2Fit deliverables

Factory2Fit deliverable 1.2 describes initial industrial requirements including user needs. The user studies carried out for D1.2 have already aimed to apply the framework presented in this deliverable.

1.4 Acronyms and abbreviations

Abbreviation	Description
AAM	Automation Acceptance Model
CHAT	Cultural historical theory of activity
HAZOP	Hazard and Operability Study
JCM	Job Characteristics Model
JDS	Job Diagnostic Survey
OHA	Operational Hazard Analysis
PHA	Preliminary Hazard Analysis
RRI	Responsible Research and Innovation
SU	Systems Usability
SUS	System Usability Scale
TAM	Technology Acceptance Model

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UEQ	User Experience Questionnaire
UX	User Experience
UWES	Utrecht Work Engagement Scale
WDQ	Work Design Questionnaire

Table 1. List of Abbreviations

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2 Background

The development of Factory2Fit framework is based on several existing models regarding health and well-being in the workplace. Danna and Griffin [8] present an organizing framework that highlights the major elements of the health and well-being in the workplace (Figure 1). This framework has served as a starting point when developing the framework for Factory2Fit. It defines the starting point, 'antecedents', as (i) work setting (presenting various types of hazards to workers to cope with), (ii) personality traits (emphasising type A personality and the locus of control, referring to whether outside sources or own ability determine what happens) and (iii) occupational stress (listing several work related stress factors) as important factors affecting well-being in the workplace. According to this framework, well-being at work includes, or is intrinsically affected, by both non-work and job-related satisfactions. An important factor in well-being at work is considered to be mental and physical health in the workplace.

The state of well-being at work has, in turn, both individual consequences, which are physical, psychological and behavioural, and organisational, including health insurance costs, productivity and absenteeism as well as compensable disorders and lawsuits.

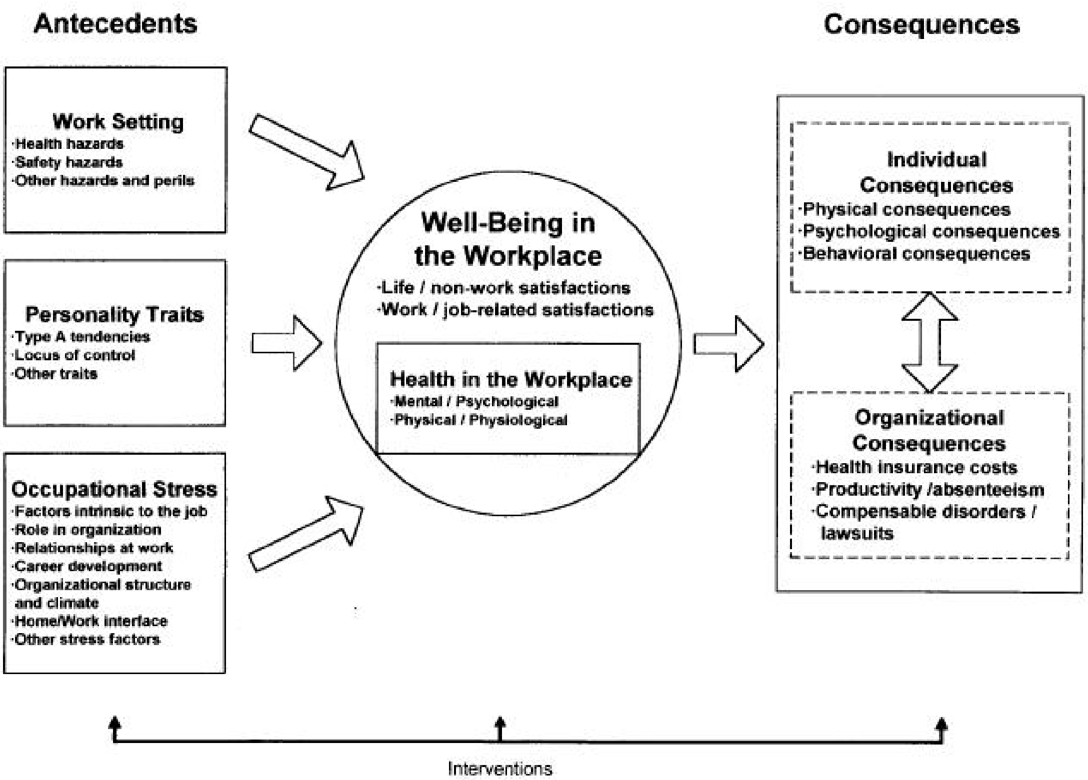

Figure 1. A framework for organizing and directing future theory, research, and practice regarding health and well-being in the workplace [8].

The framework is both rather large, including physical, psychological and behavioural aspects, and, on the other hand, restricted to scrutinise, for example, work from the viewpoint of various hazards, and

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the personality mainly from the Type A and locus of control perspectives. Thus, it does not fit very well on the approach in which work tools and other work supporting solutions are to be designed.

Based on the framework described above (see also Figure 1), Nykänen et al. [43] have proposed an conceptual model that links the physical environment through environmental satisfaction to job satisfaction and work engagement (Figure 2). This model is better compatible for the needs of Factory2Fit as the existence of physical conditions is taken into account.

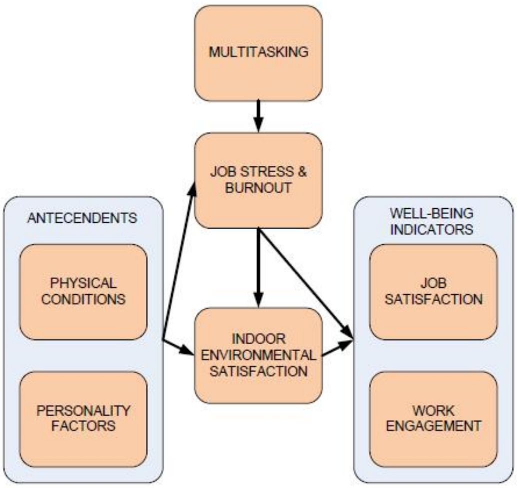

Figure 2. Conceptual model of linkages between antecedents, indoor environmental satisfaction and indicators of wellbeing [43].

Both the model by Danna and Griffin [8] and the model by Nykänen et al. [43] differentiate antecedents and consequences from the immediate implications of the intervention, i.e. the introduced new work tool or practice. Both the immediate implications and the consequences should be studied. The essential factors in both antecedents and consequences must be carefully defined to provide such a framework, which supports the (i) design and evaluation of the new tools and practices and the (ii) evaluation of their effect on well-being and company benefits. In the following section 3, such a framework, that is, the framework for Factory2Fit, is presented.

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3 Factory2Fit Work Well-Being Framework

Factory2Fit framework focuses on work well-being, from the perspectives of how it is affected by new solutions supporting work tasks and work performance, developed in the project and, on the other hand, providing means for designing and evaluating these new solutions. The effect of these solutions is also considered from the more practical perspective of company benefit.

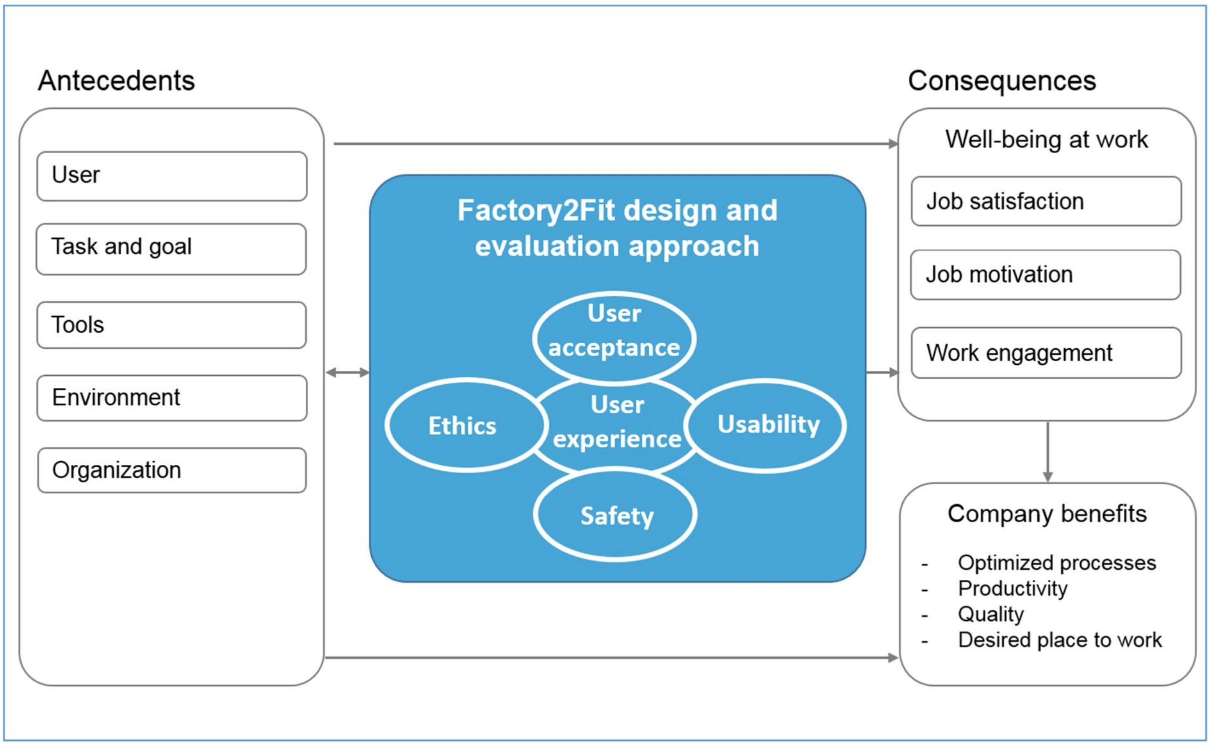

Figure 3. Factory2Fit Work Well-being Framework.

Figure 3 illustrates the proposed Factory2Fit work well-being framework. The antecedents describe the context into which we are proposing the new intervention, i.e., new work practices and the related tools. The blue square in the figure describes the approach to be used in the design and evaluation activities related to the tools and practices to be designed in the project. Thus, the Factory2Fit solutions will be designed and evaluated focusing on user experience, user acceptance, usability, safety and ethics.

The new solutions should have wider consequences on work well-being, especially on job satisfaction, job motivation and work engagement. These consequences will also be studied. Factory2Fit solutions should also lead to company benefits on optimized processes, productivity, and quality, and they should affect company image so that the company becomes as a more desired place to work. In the following, we will describe in detail the work well-being framework, focusing especially on the central design and evaluation part of it.

In addition to supporting the work to be conducted in Factory2Fit project, the Factory2Fit framework provides a new framework for studying well-being at work, based on designing new tools to support work performance in the work environment.

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3.1 Work context (antecedents)

Work context, or the constituents of "antecedents" as labelled in Figure 3, are identified on the left in Figure 3. They define the context of use according to SFS-EN ISO 9241-210: Ergonomics of human-system interaction. Part 210: Human-centred design for interactive systems: "The relevant characteristics of the users, tasks and environment which identifies which aspects have an important impact on the system design" [29]. The antecedents describe the original situation into which we design new work practices and tools in Factory2Fit. When the new solutions are used at work, they are part of the work context.

Based on the standard, the context of use description shall include the following: (1) the users and other stakeholder groups; (2) the characteristics of the users or groups of users; (3) the goals and tasks of the users, and (4) the environment(s) of the system. We have extended the environment to the physical environment, the organizational environment and the tools in use. Work context provides the field to work, the restrictions and possibilities, into which the new solutions are to be created. Work context is described in the user studies and is taken strongly into account when developing the new solutions, but strictly speaking, it is not evaluated. Instead, the usage of tools and work practises as a whole are focused on from the perspective of new solutions, described in the following section.

3.2 Design and evaluation of Factory2Fit solutions

In the middle in Figure 3 (blue coloured square) we illustrate the design and evaluation viewpoints to be used when designing and evaluating individual Factory2Fit solutions such as adaptation solutions, training and knowledge sharing. These viewpoints include

- User experience
- User acceptance
- Usability
- Safety
- Ethics

User experience focuses on how the worker feels while working. User acceptance studies factors that positively or negatively affect the adoption of new work practices and tools. Usability focuses on how appropriate the new tools are for the work and influences job performance. Safety studies ensure that existing standards and norms are followed and also identifies and solves potential new risks. Ethics focuses on identifying and solving early ethical concerns. In the following, we describe each of these viewpoints and their role in the design and evaluation activities.

3.2.1 User experience

Good user experience (UX) is nowadays the goal of most products and services intended for the consumer market. UX is also receiving increasing attention in the development of industrial products and services. According to Hassenzahl [21], user experience consists of both the pragmatic and hedonic aspects of product use. Similarly, Mahlke [37] sees user experience as stemming from the instrumental and non-instrumental qualities of product use. The pragmatic or instrumental refers to the utilitarian aspects, such as usefulness and ease of use, and hedonic or non-instrumental to the emotional and experiential aspects of product use.

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In terms of user experience with newly developed products or systems, further dimensions of user experience might become relevant. Such dimensions are attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty [34] as well as hedonic and pragmatic dimensions [22]. An experience goal describes the intended momentary emotion or the emotional relationship or bond that a person has towards the designed product or service [36].

Experiences with interactive products and services are context-dependent, dynamic, and subjective [47]. Kaasinen et al. [31] propose user experience goals to guide the design of industrial systems, and to concretise the intended experience. They propose five different approaches to acquiring insight and inspiration for UX goal-setting: Brand, Theory, Empathy, Technology, and Vision. Each approach brings in a different viewpoint, thus supporting the multidisciplinary character of UX. The Brand approach ensures that the UX goals are in line with the company's brand promise. The Theory approach utilises the available scientific knowledge of human behaviour. The Empathy approach focuses on knowing the actual users and stepping into their shoes. The Technology approach considers the new technologies that are being introduced and their positive or negative influence on UX. Finally, the Vision approach focuses on renewal, introducing new kinds of user experiences. In the design of industrial systems, several stakeholders are involved and they should share common design goals. Using the different UX goal-setting approaches together brings in the viewpoints of different stakeholders, thus committing them to UX goal-setting and emphasising user experience as a strategic design decision.

Roto et al. [46] introduce a more generic term 'experience goals' (Xgoals). They have studied how Xgoals work in actual design processes. They found that the experience goals work throughout the design process: in the requirements definition phase they give a framework for user studies; in design activities, high-level Xgoals help to create and maintain an experience mindset within the design team, and finally in evaluation activities Xgoals can be utilised in planning evaluation and as evaluation criteria.

User experience (UX) is our main viewpoint in the design and evaluation activities. Based on user studies and the aims of the technology development, we will define concrete UX goals that will guide the design and development of the solutions (including both work practices and tools). In short, the UX goals define how the user would like to feel while working. This can include goals such as Sense of control, Feeling of presence, Trust, Achievement, Competence and Being part of a community [46].

3.2.2 User acceptance

Technology acceptance models aim at studying how individual perceptions affect the intentions to use information technology as well as the actual usage (Figure 4).

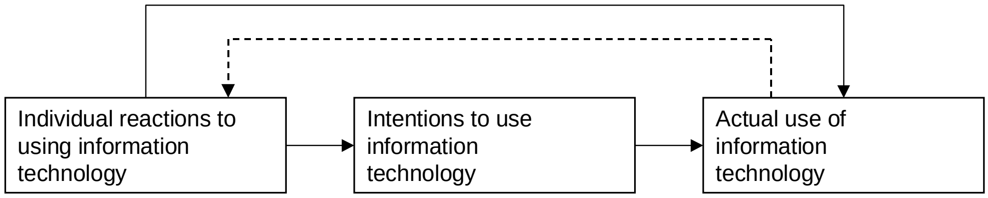

Figure 4. The basic concept underlying technology acceptance models [61].

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In 1989, Fred Davis presented the initial Technology Acceptance Model (TAM) to explain the determinants of user acceptance of a wide range of end-user computing technologies [9]. TAM points out that perceived ease of use and perceived usefulness affect the intention to use (Figure 5). Davis [9] defines perceived ease of use as "the degree to which a person believes that using a particular system would be free from effort" and perceived usefulness as "the degree to which a person believes that using a particular system would enhance his or her job performance". Perceived ease of use also affects the perceived usefulness (Figure 5). The intention to use affects the real usage behaviour. TAM was designed to study information systems at work to predict whether the users will actually take a certain system into use in their jobs. The model provides a tool to study the impact of external variables on internal beliefs, attitudes and intentions.

TAM deals with perceptions; it is not based on observing real usage but on users reporting their conceptions. The instruments used in connection with TAM are surveys, where the questions are constructed in such a way that they reflect the different aspects of TAM. The survey questions related to usefulness can be, for instance: "Using this system improves the quality of the work I do" or "Using this system saves my time". The survey questions related to ease of use can be, for instance: "The system often behaves in unexpected ways" or "It is easy for me to remember how to perform tasks using this system".

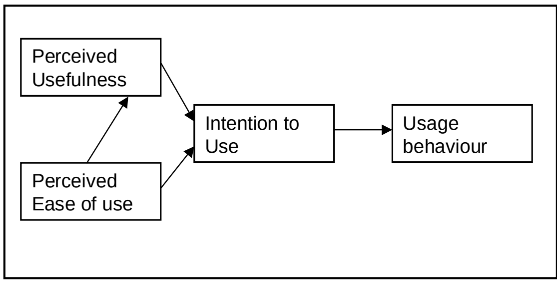

Figure 5. Technology Acceptance Model [9].

The TAM constitutes a solid framework to identify issues that may affect user acceptance of technical solutions in work. Davis and Venkatesh [10] have proved that the model can be enhanced from the original purpose of studying user acceptance of existing products to study planned product concepts, e.g. in the form of mock-ups.

Ghazizadeh et al. [17] have extended TAM to assess automation by introducing Automation Acceptance Model (AAM). The extended model includes trust and compatibility that both affect perceived usefulness and perceived ease of use (Figure 6). Trust refers to user's trust in automation and it is determined by systems performance and user's past experiences. On one hand, compatibility refers to job relevance, i.e. whether the proposed system addresses the specific task related needs of the user. On the other hand, compatibility refers to user's past experiences of automation and how well the system fulfils his/her expectations. Compatibility depends on system design and task context as well as the level of autonomy and authority granted for automation. The AAM model also introduces feedback mechanism, shown in Figure 6 as dashed arrows.

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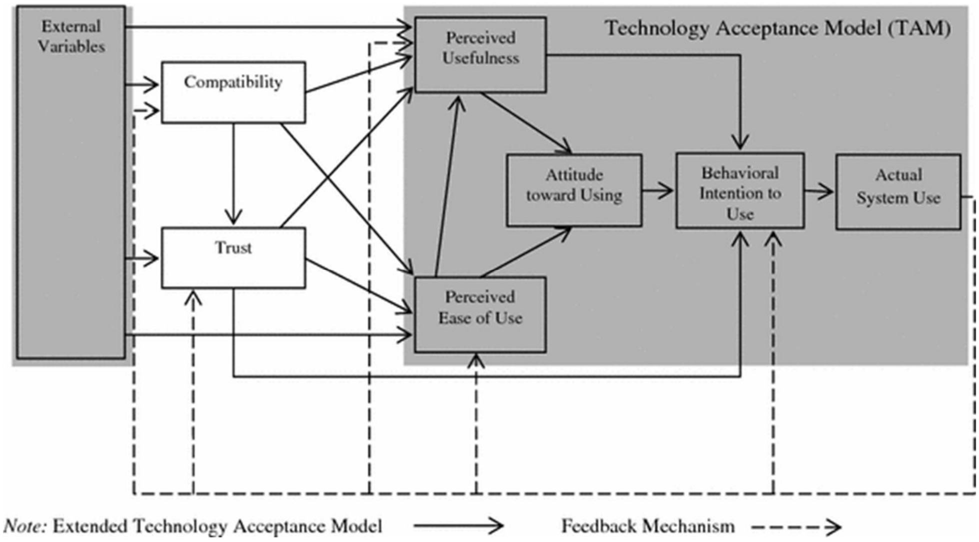

Figure 6. Automation acceptance model [17]. *Feedback mechanism is presented as dashed arrows.*

Different aspects of acceptance will be in an important role within the Factory2Fit project. According to Kollmann [32], the usage level is one important indicator for acceptance besides the assessment acceptance (that is done before the technology is implemented into use). His definition of acceptance widens the view on acceptance and can serve as theoretical basis for investigating user acceptance.

Especially for new information and communication technologies, the UTAUT2 model [62] that includes TAM as well as other theoretical frameworks (e.g., Theory of Planned Behaviour)[1], could be used to assess drivers and barriers for acceptance of the newly developed solutions. In detail, performance expectancy, effort expectancy, social influence, facilitating conditions, hedonic motivation, and habit could be relevant factors influencing workers' intention to use the technology or solution as well as actual usage.

3.2.3 Usability

In complex industrial work activity that can often be defined as safety critical, a good quality of working environment and tools is essential. But how to define and characterize "good" tool that appropriately serves its purpose and helps the user to reach the goals of the activity? The fundamental starting point for understanding the appropriateness of the tools in industrial production processes begins by investigating what is, in general, the purpose and meaning of the tools in human use. Cultural historical theory of activity (CHAT) has been utilized to understand the role of tools in activity and it forms a main foundation for the concept of systems usability (SU). Moreover, in the context of complex socio-technical systems the approach to usability needs to be systemic, that is, a multiple viewpoints and abstraction levels are included in the constellation of the concept of SU [49].

In activity theory, one main principle is that of mediation. Vygotsky [63] has explained the basic role of tool (or sign in activity). According to Vygotsky, the relationship between the subject and the target of work (object she/he is acting on) is mediated by tools and instruments. In Factory2Fit context, the subject is an individual worker, the object is the controlled factory process, and the main tools are the automation and control user interfaces in the factory. The purpose of a particular tool, for example the automation system, is to provide the object to the worker in a way that enables appropriate acting on the process.

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Based on the activity theory, the tool mediation can be elaborated by making distinction between the different functions of a tool: the instrumental, psychological and communicative functions [49,50]. Instrumental tool function refers to the tool's ability to produce intended effect in the environment. The psychological tool function refers to the possibility of external control and development of behaviour that tools (including concepts) enable. The communicative function highlights the role of the tool as a medium, or a vehicle of development of collaborative social activity and shared meaning. These functions can be evaluated from different perspectives: performance, way of acting, and user experience (for a figure describing the main constituents of the framework, see Figure 7).

Figure 7. Systems usability framework [49].

The definition what constitutes a good tool starts with the claim that a good tool needs to fulfil the functions described above. Accordingly, the better the tool fulfils the above functions the better the tool is for its use. How should we then study and identify the goodness of a tool? The most obvious way to do this is to observe how well the tool enables the worker to master the object of activity i.e., how well the factory process control is performed. Different kind of outcome criteria may be defined for the performed activity such as error count and time recordings.

Measuring the performance is maybe the most traditional way to assess the success of the design solutions, but it is not sufficient only to rely on that aspect in the context of complex system design and evaluation. That is why, SU extends the view on the aspects of activity that may be relevant to consider. Analysis of the way of acting provides the second perspective on analysis of activity. Studying way of acting helps in answering the question of how the performance outcome was achieved. Often technical, organizational and training-related barriers have been tried to design so that they neutralize the possible performance variance. Thus, performance outcome as measure is not sensitive to variance in the tools. It is also known that well-trained workers may be able to reach good outcomes even with poor designed tools and that the workers themselves recognize that there are different ways of accomplishing the same work tasks, some being better than the others in meeting the general demands of the activity. This is why it is important to also analyse the work from the way of acting point of view [42].

The third perspective to analyse work activity and tools is user experience. Not being the expert in the domain (like worker performing that specific work), external observer may not be able to comprehend the full potential of the suggested new tools and work practices. Therefore, the expertise of the professional workers concerning the appropriateness of the tools must be exploited as one perspective of the investigation and it may be labelled the user experience perspective (i.e., feelings and emotions that the tool evokes in the user).

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The two dimensions introduced above, that is, the measuring the performance and studying user experience, the three functions of a tool (instrumental, psychological, and communicative) allow to state that *the SU denotes the capability of the technology to fulfil the instrumental, psychological, and communicative functions of a tool in the activity and to support fulfilment of core-task demands in the work. SU is evidenced in technology usage in appropriate performance outcome, way of acting and user experience*.

In the Factory2Fit project, the level of SU of the different Factory2Fit solutions will be studied with the systems usability questionnaire (described in more detail in Chapter 4 Methods and tools).

3.2.4 Safety

In the design phase of machinery, the design for the safety is based first on requirements, which cover typical risks. However, there are no requirements that cover all safety aspects of all kinds of machinery as machines can vary quite intensively. Therefore, secondly, risk assessment, which covers new and unusual risks and specifies more accurately the typical risks is needed to perform. It is the only way to guarantee that the risks are defined more appropriately and precisely.

One aim of the requirements is to have similar (low) risk in similar machines in order to trade freely machines inside EU market. The safety requirements for machinery are the same in EU (Machinery Directive and harmonized standards) and therefore the safety requirements do not prevent the trade. According to official guide of the Machinery Directive: "The Machinery Directive thus has a dual objective: to permit the free movement of machinery within the internal market whilst ensuring a high level of protection of health and safety" [16]. Actually, the safety requirements are an agreement of acceptable risk levels. However, the requirements are not always adequate from the safety point of view and risk assessment is needed to see specific risks, which are not covered by standards. One can say also that bad requirements cannot be an excuse for poor safety from the liability point of view. Error! Reference source not found.8 shows, which requirements and procedures need to be considered when designing machinery. The solid lines describe obligatory aspects for all machines and dotted lines aspects, which are relevant in many automated machines.

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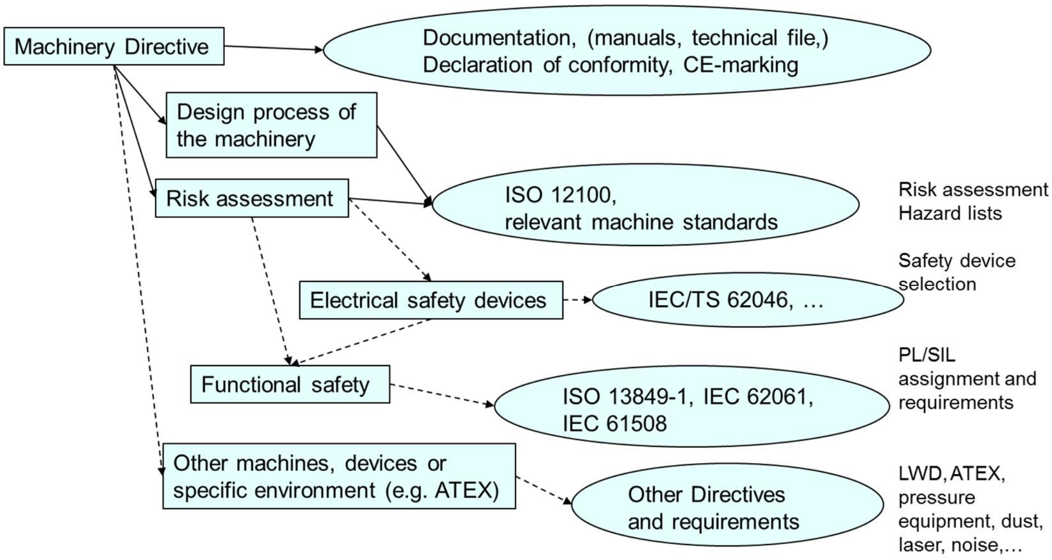

Figure 8. Safety design process for automated machines.

The most important goal in risk assessment is to identify all potential risks that all potential risks are found. If there is a risk, which is not considered, the risk cannot be controlled. Another important factor is objectivity, i.e., the results should be similar when the risk assessment is done by another person. This can be challenging. One way to improve objectivity is to compare results first to harmonized standards (they fulfill the relevant requirements of the Machine Directive) and then to other similar systems, other standards and guidelines. Error! Reference source not found.9 shows the phases of risk assessment process and the risk reduction of machinery (risk management). The risk reduction phases are prioritized so that first inherently safe means are applied (i.e. risk is removed), and then safeguarding, which includes adding/implementing safety devices and guards. If safety issues exist that cannot be resolved, although the mentioned technical means are applied adequately, then machine users must be informed about those risks b using manuals, warnings and/or training.

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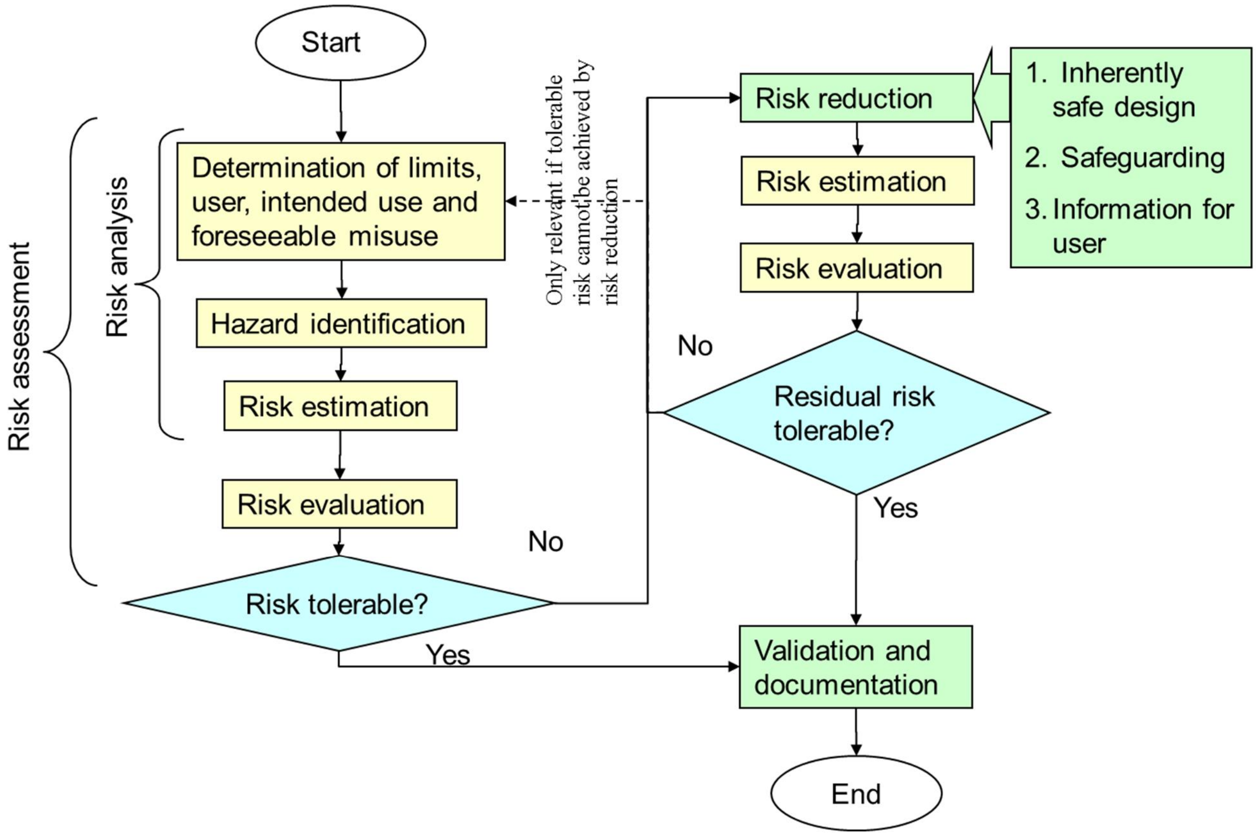

Figure 9. Risk management process for machinery [13]

For automation, safety devices and control systems, the risks related to safety functions are categorized in order to be able to compare risks. The higher risk the more intensive means are needed to minimize the risk. A probabilistic approach is applied in comparing the risk reduction rate of the safety functions. Safety integrity levels (SIL, from 1 to 3) or Performance levels (PL, from a to e) (SFS-EN ISO 13849-1, 2015) [14] are applied first to determine the safety requirement level and later to define the risk reduction level of the control system or actually control function. The SILs are associated to probability of dangerous failure per hour (high demand mode) and for SIL 1 value is from 10^{-6} to 10^{-5} and for SIL 3 from 10^{-8} to 10^{-7} (IEC 61508-1, 2010) [26]. The PLs can be associated to equivalent SILs and both categorizing methods can be applied also inside the same system. In process industry and some other branches of industry, probability of dangerous failure is applied (low demand mode) and there is also SIL 4 to minimize catastrophes.

The risk is divided into two different perspectives: the severity and the probability of the risk. The probability is further divided into frequency, exposure time, probability of the occurrence and possibility to avoid the hazard. The possibility to avoid the hazard is related also to the awareness and skills of the worker. Therefore, it is allowed to share part of safety responsibility between automation and awareness system (including a human being) in cases where the importance of situational awareness is high and it is possible to measure and improve the awareness. Typically, the means for supporting situational awareness are applied in cases where human is good in perceiving and understanding the safety issues of the system.

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Automated systems are often very quick and a human being is not quick enough to prevent hazards. For example, emergency stop is obligatory in most of the automated systems, but it cannot substitute other safety means. One reason is that automation is quicker than human, meaning that the human action of pushing a button may be too slow relative to the automation producing quickly the unwanted outcome. Another reason is that human is not always there to see a safety issue, whereas automation can monitor the system continuously; in some types of malfunctioning, automation is able to detect and prevent an accident when the human user cannot. The problem is that automation capable of identifying all types of risks and acting on them accordingly does not exist. Thus, emergency stop is good to have, since typically, the emergency circuits are simple and they can save the situation even if all the other systems fail. More detailed requirements for integrated manufacturing systems are described at ISO 11161. The standard covers, among others, robot systems, which include several machines [28].

3.2.5 Ethics

Ethics of emerging technologies is a subject of double uncertainty – first, in regard to a potentially infinite number of technical possibilities, their applications and uses, and, second, in regard to a potential infinity of ethical issues that arise from each technology [57].

In European governance of science and innovation, there is an emerging initiative of Responsible Research and Innovation (RRI). Responsible innovation refers to "taking care of the future through collective stewardship of science and innovation in the present" [59] and promotes reflective and inclusive research and innovation activities [12]. RRI concerns all levels of innovation: from entire innovation systems down to project level.

Niemelä et al. [41] propose Ethics by Design approach that aims to advance RRI in the daily project work. The heart of Ethics by Design is positive, forward-looking and proactive ethical thinking. Ethical points of view are considered in the early project phases, with the aim of creating a positive, ethical-solution-oriented mind set among project partners. The ethical approach should not just identify current or future problems but actively design for and be inspired by achieving ethically sustainable solutions [12]. The ethical perspective is brought by ethical experts, for instance, in the form of an ethical advisory board that participates in the development from the very beginning of the project.

An essential dimension of Ethics by Design is the inclusion or involvement of stakeholders. Ethical perspectives are identified, opened and co-constructed with technology developers, domain experts, potential end-users and other relevant stakeholders, and ethical solutions are sought together. Ethics by Design should produce ethical design solutions, but, perhaps even more importantly, produce or encourage mutual learning by participants about ethical issues around technology development. This aligns well with the goals of RRI: in the future, ethical thinking, reflection and negotiation will be part of the mind-set of the designer, developer and end-user. Nowhere can we expect fixed, universal ethical solutions; rather, they are described as contextual, case-specific, transient and negotiable over and over again [57].

Ethics by Design approach [41] encourages active interaction between developers, utilisers and ethical expert. The developers and experts together should draw up an ethical action plan for the project. In the plan, different ethical approaches can be named and scheduled:

- Ethical design methods

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- Ethical impact evaluation
- Inclusion activities and methods
- Ethical communication within the project
- Ethical guidelines introduced into the project work

The ethical plan can also include directions on what to do if there is a risk that the development work stops because of an ethical conflict. The plan needs to be re-defined regularly during the course of the project.

In our design and evaluation framework, ethical issues are included in the design and evaluation activities. Initial ethical guidelines are based on Ethical guidelines for ambient intelligence [27] and they include:

Privacy: An individual shall be able to control access to his/her personal information and protect his/her own space.

Autonomy: An individual has the right to decide how and for what purposes he/she uses technology.

Integrity and dignity: Individuals shall be respected and technical solutions shall not violate their dignity as human beings.

Reliability: Technical solutions shall be sufficiently reliable for the purposes for which they are being used. Technology shall not threaten the user's physical or mental health.

Inclusion: Services should be accessible by all user groups despite their physical or mental deficiencies.

Benefit to society: Society shall make use of the technology to improve quality of life and not cause harm to anyone.

In the concept design, the guidelines can be used as a checklist: What are potential privacy threats? How can we ensure privacy? How about autonomy? - and so on. The proposed solutions can also be assessed against these guidelines by the design team. In the evaluation activities, the guidelines constitute a list of ethical themes to be included in the evaluations with users.

3.3 Impacts on work well-being

On the right side of Figure 3, we illustrate the foreseen the wider areas of impact of Factory2Fit solutions on work well-being. These are studied in impact assessment (WP6) but they may also be touched when evaluating individual Factory2Fit solutions.

3.3.1 Job satisfaction

The two most common definitions for job satisfaction describe it as: "a pleasurable or positive emotional state resulting from the appraisal of one's job or job experiences" [35] and "the extent to which people like (satisfaction) or dislike (dissatisfaction) their jobs" [56]. Job satisfaction can be

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considered as an overall attitude towards work in general, or in relation to different aspects of work, such as, colleagues, salary, the nature of work itself, supervision, or working conditions [56]. The extent to which work properties meet or exceed the personal expectations of employees determines the level of job satisfaction [35]. Satisfaction with the nature of work, including job challenge, autonomy, variety and scope, predicts best the overall job satisfaction [48].

Job satisfaction may predict absenteeism [65] and the turnover intentions of employees [6,48]. In addition, employees with high job satisfaction seem to return faster back to work after physical (e.g. musculoskeletal and back) injuries [15,25].

3.3.2 Job motivation

Porter and Lawler [44] divided work motivation into intrinsic and extrinsic motivation. If workers fulfil their tasks because they derive spontaneous satisfaction from fulfilling the activity itself and are interested in this work, they are intrinsic motivated. Extrinsic motivation, in contrast, describes that workers' satisfaction comes not from their tasks, it rather comes from the consequences that go along with the fulfilment of the task, such as verbal or financial rewards. The distinction already points on the close relationship between work motivation and satisfaction.

Herzberg's motivation-hygiene theory [24], also known as the two-factor theory, is another widely known practical approach towards motivating workers. He defined motivators that involve factors determined by the job itself such as achievement, recognition, responsibility, and advancement. Besides that, hygiene factors are extrinsic to the job, such as interpersonal relations, tips, salary, supervision and company policy. The theory proposes that hygiene factors are necessary to prevent negative feelings and dissatisfaction; the existence of motivators determine satisfaction.

Hackman and Oldham [18] proposed a model, the Job Characteristics Model (JCM), which combines the job motivation and satisfaction within one model. According to this model, satisfaction with the work, together with other important job related outcomes, occur when the work is intrinsically motivating. The degree of motivation depends on whether 1) the work is experienced as personally meaningful, valuable and worthwhile, 2) employees perceive themselves as personally accountable and responsible for the work outcomes, and 3) employees are aware how well they perform in their work (Figure 10).

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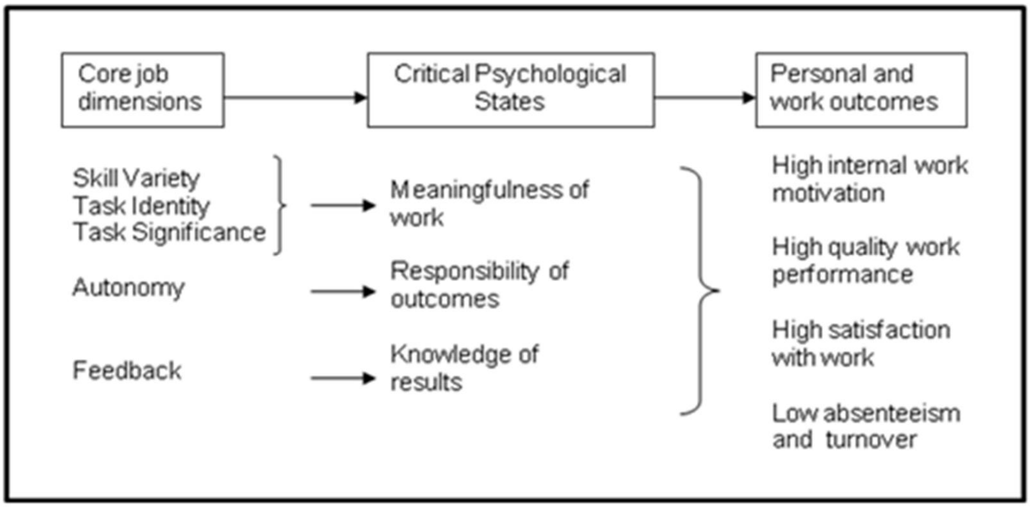

Figure 10. Job characteristic model [18].

According to the authors a motivational score of the work could be calculated using the formula presented in Formula A.

Formula A

$$Motivating\ potential\ score = \frac{Skill\ variety + Task\ identity + task\ significance}{3} * Autonomy * Feedback$$

3.3.3 Work engagement

The concept of work engagement has been defined by two different ways. First, Maslach and Leiter [39] defined work engagement to refer to energy, involvement and professional efficacy, which they see as direct opposites to the characteristics of burnout (exhaustion, cynicism and lack of professional efficacy). Opposite to that, Schaufeli et al. [53] consider the work engagement and burnout as independent states, not the direct opposites in the same continuum. According to them, work engagement is defined as "a positive, fulfilling, work-related state of mind, which is characterized by vigor, dedication and absorption". It is not a momentary state, but a more persistent affective-cognitive state, which is not focused on any specific object, event, individual or behaviour. Because of this, work engagement is likely to remain relatively stable over time.

According to the characterisation by Schaufeli et al. [53], an engaged worker is vigorous: feeling energetic while working and being willing to invest effort in one's work. Vigor is also reflected as persistence when facing difficulties. An engaged worker is also dedicated in one's work, feeling a sense of significance, enthusiasm, inspiration and pride. A third dimension, absorption, is characterised as being fully concentrated and deeply engrossed in one's work, which may make detaching from work difficult. Absorption can be associated to flow state [7], an optimal mental state of being completely present and fully immersed in a work task. The characterisations are close to each other, but the difference is that the flow state is a momentary state ("peak experience") unlike engagement.

According to JD-R model of work engagement (Figure 11) [3], both job resources and personal resources predict work engagement, having a positive impact on it especially when the job demands are high. Work engagement has a positive impact on performance at work. When the workers are

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engaged and perform well, they are able to create and strengthen their resources, which creates a positive spiral.

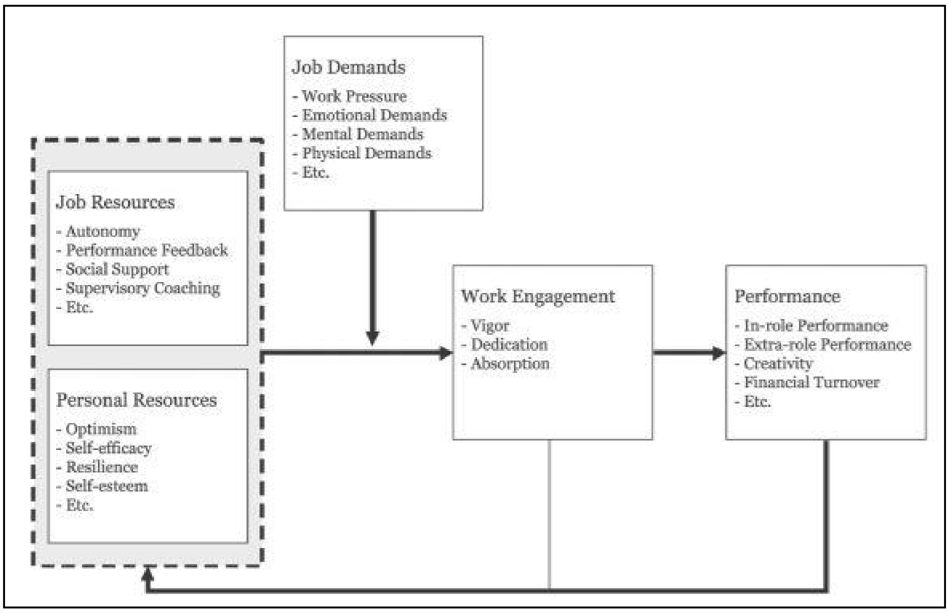

Figure 11. The JD-R model of work engagement [3].

3.4 Company benefits

Factory2Fit solutions that increase work well-being will also have impacts on company level, presented on the right lower side of Figure 3. According to the framework, company benefits, based on the new solutions, origin from the efficiency of the new solutions on work output directly and from the increased wellbeing at work. This means, essentially, that Factory2Fit solutions are estimated to produce better work performance and better well-being at work independently but that these two matters, advanced work context and better well-being at work, also strengthen each other in producing new or enhanced company benefits.

The expected impacts include (i) optimized processes in the proceeding of the work; (ii) higher productivity; (iii) quality improvements, and (iii) the improvement image of the company, making it as a desired place to work.

These impacts can be really studied only after the Factory2Fit solutions have been implemented to the company processes, but the expectations about them, set by the company representatives, can be assessed also beforehand, when nothing has changed in the work place.

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4 Methods and tools

In this section, we briefly present design and evaluation methods and tools that are potentially applicable to Factory2Fit design and evaluation activities. Table 2 presents an overview of the methods. Only such methods are mentioned which are potential for the project work, not a comprehensive list of all methods. The list will be refined in the progress of the project so that the different data assessing parties within the project are enabled to use the methodology originating from this same pool, resulting in high-quality solutions and, preferably, also comparable data obtained from the diverse sources.

	Research subject	Method/approach	Description	Proposed by
1. User experience				
1.1	UX evaluation	Interview (theme), emocards	Experience and conception related questions, emocards to get quick feedback on user feelings [11]	VTT
1.2	UX of interactive products	AttrakDiff	Questionnaire investigating UX on hedonic and pragmatic dimensions [23]	TUC
1.3	UX of interactive products	UEQ – User experience questionnaire	Questionnaire investigating 6 factors: Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, and Novelty [34]	TUC
1.4	UX goals	Setting concrete goals for targeted UX	Combining information from several viewpoints and several stakeholders to set the UX goals [31]	VTT
2. User acceptance				
2.1	Automation Acceptance Model (AAM)	AAM questionnaire	Studies perceived usefulness, perceived ease of use, compatibility and trust [17]	VTT
2.2	Unified theory of acceptance and use of technology	UTAUT2 questionnaire	UTAUT includes various theories such as TAM, TPB; UTAUT 2 is modified and habits are included [62]	TUC

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	Research subject	Method/approach	Description	Proposed by
2.3	Acceptance (attitudes)	Van der Laan acceptance scale	questionnaire with to scales assessing Usefulness of and Satisfaction with a product [33]	TUC
2.4	Acceptance behavior	Observation, data logging	Collecting usage rates or resistance of usage after implementation	TUC
3. Usability				
3.1	Systems Usability	Systems Usability questionnaire	Original, to be modified according to the tool in question (e.g., [50,51])	VTT
3.2	System usability	System usability scale	For developed products, 10 items, quick and dirty usability scale (SUS, [4] [5])	TUC
3.3	Usability	Usability questionnaire according to ISONORM	Suitability for the task, Self descriptiveness, Controllability, Conformity with user expectations, Error tolerance, Suitability for individualization, Suitability for learning (according to ISONORM 9241/10 [45])	TUC
3.4	Usability	Usability test (lab)	Collecting difficulties in usage/handling of new development, number of mistakes, needed time for fulfilling tasks while testing a new device/solution/service	TUC
3.5	A subjective workload assessment tool	NASA Task Load Index (TLX)	Questionnaire about various dimensions of workload, based on self-assessment [20]	VTT
4. Safety				
4.1	Risk assessment	PHA – Preliminary Hazard Analysis, OHA – Operational Hazard Analysis	Three-step assessment of safety risks in automated mobile work-machine systems [60]	VTT

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	Research subject	Method/approach	Description	Proposed by
		HAZOP (Hazard and operability study)		
5. Ethics				
5.1	Ethics by design	Ethical guidelines	Planned designs are assessed based on the guidelines. Questionnaires based on the guideline themes [27]	VTT
6. Well-being				
6.1	Well-being and health	Physiological data measurement	Heart rate, stress, sleep parameters	TUC
6.2	Well-being and health	Warr's Questionnaire	Affective well-being and other aspects of health [64]	TUC
7. Job satisfaction				
7.1	Job satisfaction	Andrew and Withey Job Satisfaction Questionnaire	Global job satisfaction, 5 items [2]	TUC
7.2	Job satisfaction	Job satisfaction survey	Assessment of satisfaction and influencing factors (i.e., job characteristics, psychological states, affective responses to the job, growth need strength) (JDS,) [18]	TUC
8. Job motivation				
8.1.	Job motivation score + intrinsic motivation	Job Diagnostic Survey (JDS)	Assessment of intrinsic job motivation as part of the questionnaire; based on the questionnaire results a score for potential motivation through the job can be calculated (JDS,) [18]	TUC
9. Work engagement				
9.1	Work engagement	Utrecht work engagement scale (UWES)	Questionnaire measuring the dimensions of work engagement (vigor, dedication and absorption): Schaufeli et al. [53]	VTT
10. Facilitating factors				

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	Research subject	Method/approach	Description	Proposed by
10.1	Facilitating factors	Job diagnostic survey	Assessment of satisfaction and influencing factors, i.e., job characteristics, psychological states, affective responses to the job, growth need strength; originally JDS [18], German version [55]	TUC
10.2	Facilitating factors	Work Design Questionnaire (WDQ)	Questionnaire, based on the JDS; 21 items assessing task, social and knowledge characteristics as well as work context; originally Morgeson & Humphrey [40], German version [58]	TUC

Table 2. Overview of potential methods and tools.

4.1 User Experience related methods

4.1.1 Emocards

Emocards provide a non-verbal method for users to self-report their emotions. Different emotions are described as human faces/images on separate cards or on a single sheet of a paper. After completing a task or periodically, the person is asked to pick one of several emotion cards that reflect how they are feeling about interacting with the system to be evaluated. This method can be utilised to complement UX evaluations with quantitative results.

4.1.2 UX Goals

UX Goals concretize what kinds of feelings the system optimally would evoke in users. The goals are set in collaboration with different stakeholders based on information from various sources. Figure 12 illustrates the different viewpoints. Kaasinen et al. [31] identify the following viewpoints in UX goal-setting:

1. The brand-based approach is based on the idea that user experience of products should be in line with brand experience, the image that a company wants to convey to its customers.
2. Psychological theories can be used to explain why some experiences are satisfying and engaging for a user.
3. By understanding users with empathy, the designers can obtain inspiration for products and services that provide good user experience.

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4. User experience goals help in drawing one's attention to the positive experiences that a new technology can facilitate and, on the other hand, user experience goals can focus on minimising the anticipated negative experiences such as a lost sense of control or a lost feeling of presence.
5. Sometimes UX inspiration comes from investigating the deep reasons for product existence and envisioning renewal: vision from desirable possibilities, often taking inspiration from other fields.

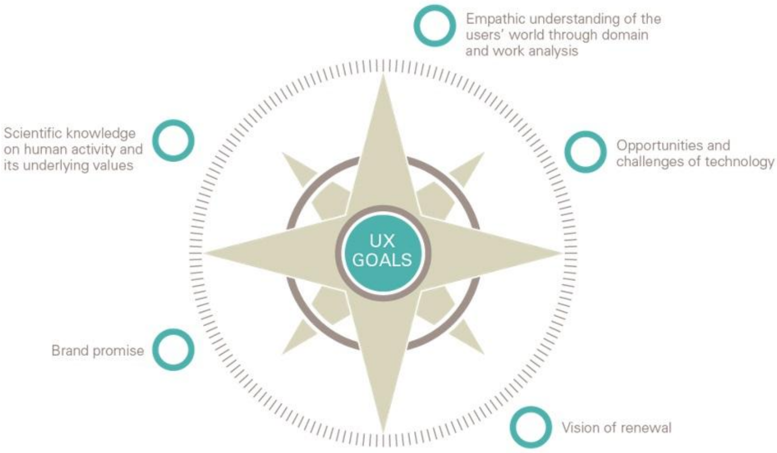

Figure 12. Viewpoints in UX Goal-setting (Kaasinen et al., 2015)[31]

The interplay between the different UX goal-setting approaches supports the multidisciplinary nature of UX and gives different stakeholders possibilities to contribute to the goal-setting. Using multiple approaches can produce multiple, even conflicting UX goal candidates. On the other hand, the different approaches may reveal similar goals, which gives evidence of the importance of those goals. Focusing on a few user experience goals helps in sharing the selected user experience goals, committing the design team to those goals, and keeping those goals in everyone's mind throughout the design process.

In earlier work, UX goals for human-automaton collaboration have included e.g. [46]:

- Trust in automation,
- Sense of freedom,
- Ownership of the process,
- Relatedness to the work community

Once the UX Goals have been set, they can be utilised in evaluation activities. The evaluations can then study whether the intended experiences come true, but also whether the set UX Goals were what the users actually are expecting.

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4.2 User acceptance related methods

4.2.1 Automation Acceptance Model

The method is used to assess user acceptance of proposed changes to the automation system and user interaction with it and related tools. A questionnaire includes questions related to perceived usefulness, perceived ease of use, compatibility and trust. The respondent assesses different qualities on the scale 0-5 or 0-7. Combining the results with background questionnaires on user characteristics can reveal differences in acceptance between different user groups [17]. AAM is based on technology acceptance models. Figure 13 presents one example of what kinds of results TAM questionnaires can produce.

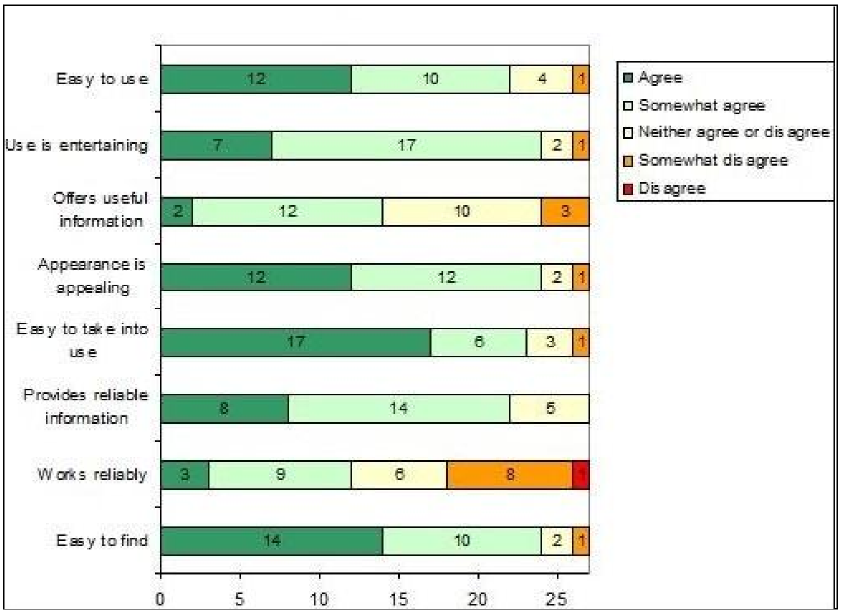

Figure 13. An example of TAM questionnaire results [30].

4.2.2 Acceptance of newly developed tools

The van der Laan Acceptance Scale [33] assesses satisfaction and usefulness of a product or tool and is a very economic method to assess workers' general attitude towards newly developed tools. The UTAUT2 questionnaire covers more influencing factors that influence acceptance of new technology. In detail, performance expectancy, effort expectancy, social influence, facilitating conditions, hedonic motivation, and habit will be assessed that potentially influence workers' intention to use the technology or solution as well as actual usage. As a behavioural indicator for acceptance, usage rates or resistant measurements have great potential when alternative ways for working exist that do not include the usage a newly developed tool. Therefore, collection of actual usage data should be aimed.

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4.3 Usability related methods

4.3.1 Systems Usability

Systems Usability (SU) is a concept defining usability of a tool (machinery, software etc.) from a sociotechnical perspective. The approach is threefold by offering the perspectives of instrumental function, psychological function and communicative function for tool evaluation [38,50]. A questionnaire can be developed for the evaluation of SU from the perspective of users' experiences and the performance with the tool as well as work practises can be evaluated, if needed, by assessing and observing them. The questions are to be edited to fit the specific tool and work context in question.

4.3.2 SUS and Usability questionnaire and Lab tests

For newly developed tools or practices established scales such as the System usability scale [4] or the Usability questionnaire according to ISONORM 9241/10 [45] can be utilized. Additionally, lab tests can be conducted in order to collect difficulties in usage/handling of new development, number of mistakes, needed time for fulfilling tasks when testing a new device, solution or service.

4.4 Safety related methods

4.4.1 Risk assessment methods

It is difficult to find all relevant risks in a complex system. Therefore, it is very recommendable to apply hazard lists and different analysing methods to have different perspectives to find potential hazards. The basic hazard list for machinery is presented in the standard "ISO 12100 General principles for design. Risk assessment and risk reduction", but more detailed lists can be found at standards, which are dedicated to a specific machine. For example, standard "ISO 10218-2 Safety requirements for industrial robots - Part 2: Robot systems and integration" describes in the list the hazards most important hazards related to robot systems. Risto Tiusanen presents in his doctoral thesis [60] how risk assessment is first done according to subsystems and parts of the system (PHA – Preliminary Hazard Analysis). This gives an overview of the risks related to different parts of the system. Then OHA – Operational Hazard Analysis is made to find risks from the human task point of view. Finally, failures, deviations and human errors are considered to find hazards related to unusual situations. A typical analysing method in this phase is HAZOP (Hazard and operability study), which can consider failures, human errors and unusual performance of the worker.

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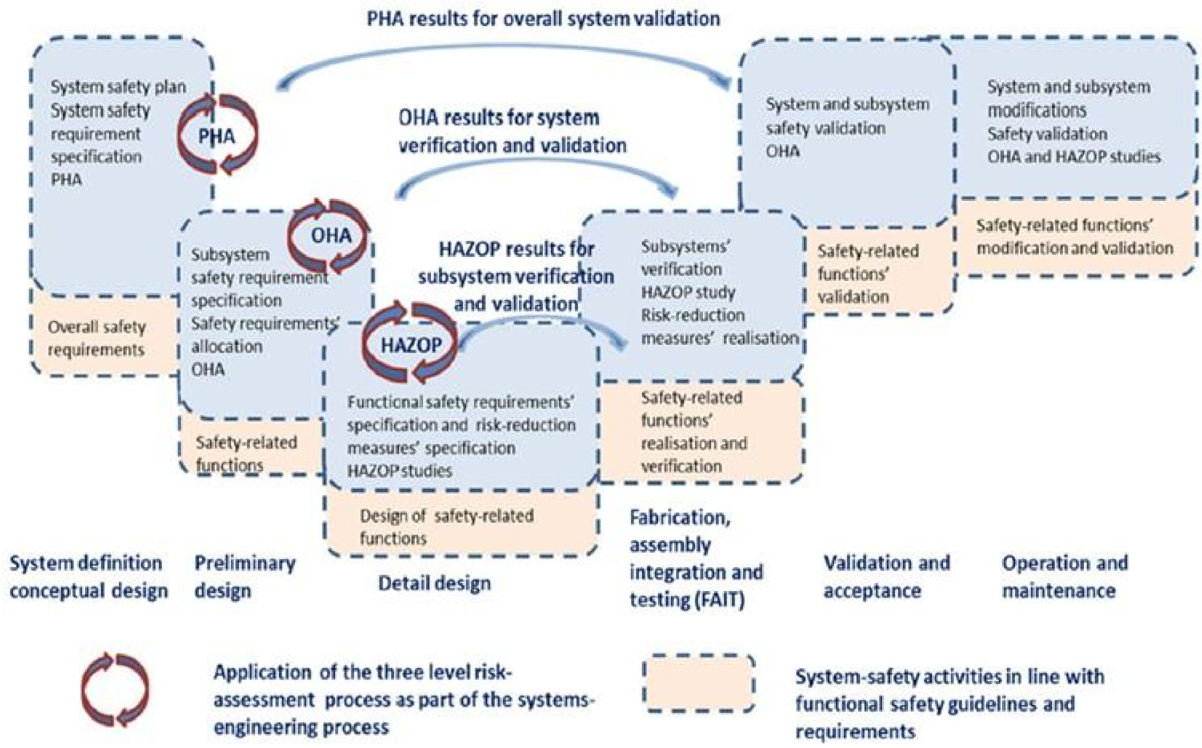

Figure 14. Application of the three level risk assessment [60].

4.5 Ethics related methods

Concrete methods for Ethics by design are still rare. The ethical guidelines proposed by Ikonen et al. [27] provide a promising starting point for Factory2Fit. The guidelines were originally designed for ambient intelligence applications but a major focus on them is on applications intended to measuring human beings and their activities. The guidelines present six ethical themes:

1. *Privacy*
2. *Autonomy*
3. *Integrity and dignity*
4. *Reliability*
5. *Inclusion*
6. *Benefit to society*

The guideline themes can be utilised in design workshops as a check list of themes to be assessed related to the designs. The guideline themes can also be used as a basis for questionnaires to support assessment of designs.

4.6 Well-being related methods

Several types of physiological measurements can be performed, related to, for example, stress or spryness (heart fate, skin conductance, sleep parameters etc.). A questionnaire type inquiry can also be used, designed by Warr [64].

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4.7 Job satisfaction related methods

There are several questionnaires concerning job satisfaction. Andrew's and Withey's Job Satisfaction Questionnaire [2] assess the global job satisfaction using 5 statements. Hackman and Oldham [18] developed the job diagnostic survey, in which not only job satisfaction is assessed, but also potential influencing factors such as job characteristics, psychological states, affective responses to the job, and growth need strength.

4.8 Job motivation related methods

Intrinsic work motivation is assessed within the Job diagnostic survey [18]. Based on the findings of the questionnaire a motivational score could be calculated using the formula presented in Formula A. Additionally, the JDS covers many of the proposed dissatisfiers and motivators described by Herzberg [24].

Formula A

$$Motivating\ potential\ score = \frac{Skill\ variety + Task\ identity + task\ significance}{3} * Autonomy * Feedback$$

Additionally, the critical psychological states (presented briefly in Figure 6, for example) can be inquired by using interviews or a questionnaire.

4.9 Work engagement related methods

4.9.1 UWES scale

Work engagement can be measured with the Utrecht Work Engagement Scale (UWES). An original version includes 17 statements [54], but also a nine-item validated and widely used version of the scale can be used [52]. The items include statements, such as "At my work, I feel bursting with energy" and "I am immersed in my work", which are rated on a scale from 0 (never) to 6 (every day). In Finland, the scale has been translated by Hakanen [19], and it can be freely used for noncommercial purposes.

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5 Conclusions

Factory2Fit Work Well-Being Framework introduces the initial design and evaluation framework to support the design and evaluation activities in the project. The framework covers immediate implications of the Factory2Fit solutions regarding user experience, user acceptance, usability, safety and ethics. In addition, the framework supports the studying of consequences of the solutions on work well-being, such as job satisfaction, job motivation and work engagement. The framework is complemented with a collection of potential methods and tools to support design and evaluation activities.

The Factory2Fit Work Well-being Framework will be developed in parallel with using it in design and evaluation activities. Based on the experiences of using the framework, the

framework will be complemented with new methods and tools, especially such that integrate the proposed viewpoints.

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